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# Contribution of starburst mergers at $z \sim 1$ to the strong evolution of infrared and submillimeter deep surveys

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**Abstract.** Recent far-infrared and submillimetre waveband observations revealed huge amount of Ultraluminous Infrared Galaxies (ULIGs) with infrared luminosities $> 10^{12}\,L_\odot$. These sources are proposed to lie at redshift above one, and normally interacting systems with very dusty environments. We discussed in a previous paper that a population of fast evolving infrared burst phase triggered by gas rich mergers at $z \sim 1$ interpreted successfully the steep slope at faint IRAS $60\,\mu m$ source counts within the flux range of $100\,mJy \sim 1\,Jy$, leaving still the infrared background level at this wavelength compatible with the upper limit from recent high energy TeV $\gamma$ ray detection of Mrk501. To extend the model to mid and far infrared wavelength, we adopt a reasonable template spectral energy distribution as typical for nearby infrared bright starburst galaxies ($L_{ir} <= 10^{12}\,L_\odot$), such as Arp220. We construct the SED for the dusty starburst mergers at $z \sim 1$ by a simple dust extinction law and a thermal continuum assumption for the far-infrared emission. Since the radiation process at mid-infrared for these starburst merging systems is still uncertain, we assume it is similar to the MIR continuum of Arp220, but modify it by the observed flux correlation of ULIGs from IRAS, ISOCAM deep surveys. We show in this paper that the strong evolution of the European Large Area ISO Survey (ELAIS) at $90\,\mu m$, ISO $170\,\mu m$ and the Submillimeter deep survey at $850\,\mu m$ could be sufficiently accounted for by such an evolutionary scenario, especially for the hump of the ISOCAM $15\,\mu m$ source count around $0.4\,mJy$. From current best fit results, we find that the dust temperature of those extremely bright starburst merging system at $z \sim 1$ would be higher than that of Arp220 for a reconciliation of the multi-wavelength infrared deep surveys. We thus propose that the infrared burst phase of dusty starburst galaxies or AGNs from gas rich mergers at $z \sim 1$ could contribute significantly to the strong evolution of the IRAS $60\,\mu m$, the ISO $15\,\mu m$, $90\,\mu m$, $170\,\mu m$, as well as the SCUBA $850\,\mu m$ number counts, meanwhile compatible with the current observational limits of cosmic infrared background and the redshift distributions. The major difference of our current model prediction is that we see a fast convergence of the differential number counts at $60\,\mu m$ below $50\,mJy$, which is about a factor of two brighter than other model predictions. Future infrared satellite like Astro-F, SIRTF would give strong constraints to the models.

**Key words.** evolution-galaxies–interaction-galaxies–starburst-galaxies–Seyfert

## 1. Introduction

There has been much progress in the extragalactic evolution study since far-infrared and submillimeter deep surveys detected a significant population of Ultraluminous Infrared Galaxies (ULIGs: $L_{ir} > 10^{12} L_\odot$) at high redshift ($z \sim 1-4$) (Dole et al. 1998, Holland et al. 1999, Hughes et al. 1998, 2000, Blain et al. 1999, Eales et al. 1999, Sanders 1999, Puget et al. 1999). The major interests of present researches are the nature and evolution of these fantastic sources. Due to lacking of high resolution morphological studies, the origin of these faint SCUBA sources are still not clearly understood as those local ULIGs, which are almost 100% certain from major galaxy mergers with high dust extinction for the central starburst or AGN activities (Sanders & Mirabel 1996, Murphy et al. 1996, Surace et al. 1998, 2000, Scoville et al. 2000). Nevertheless, more than 50% of the high redshift ultraluminous infrared objects and the optical counterparts of ISOCAM HDF-N galaxies are suggested to show the indication of galactic interactions and merger signatures (Mann et al. 1997, Smail et al. 1999, Ivison et al. 1998, 2000, Sanders 1999). Meanwhile, estimation of their spectral energy distributions suggest that these galaxies are probably the high redshift counterpart of the local ULIGs discovered by IRAS deep survey ( Barger et al. 1998, 1999, Frayer et al. 2000, Smail et al. 1998, Trentham, Kormendy & Sanders 1999). Although the last words are not ready for the formation mechanism of these interesting sources, there are certain rea-

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sons to say that majority of them may be major mergers of gas rich disks accompanied by dust-shrouded nuclear starbursts or powerful Active Galactic Nuclei (AGN). SMM J14011+0252, and ERO J164502-4626.4 (HR10) are two of such candidates with their central activities is heavily hiddened by dust extinction, and are suggested to be consistent with the evolution track of mergers–starbursts/AGN, probably elliptical galaxies in formation (Graham & Dey 1996, Cimatti et al. 1998, 1999, Dey et al. 1999, Frayer et al. 1998, 1999, Papadopoulous et al. 2001).

On the other hand, the source counts from present infrared and submilimetre survey, such as IRAS, ISO and SCUBA all significantly exceed the non-evolving predictions. The extremely strong evolution is seen from the differential counts of the ISOCAM $15\,\mu m$, with the remarkable upturn at $S_{15} < 3\,mJy$ and a fast convergence since $S_{15} \sim 0.3\,mJy$. This striking feature is based on the data from several independent sky surveys (Serjeant et al. 2001, Elbaz et al. 1999, Chary & Elbaz 2001, Mazzei et al. 2001). Although there are many other possible evolutionary scenarios which could interpret the present observations, the reason that we are encouraged to explore here a merger-driven galaxy evolution picture with the binary aggregation dynamics, is simply because IRAS database, recent ISO and sub-mm deep surveys indicate that most of the luminous infrared sources are actually interacting/mergering systems. Besides, the local IR luminosity function shows an excess over the Press-Schechter formula (Press & Schechter 1974, Lonsdale 1995, Pearson & Rowan-Robinson 1996, Roche et al. 1998, Dole et al. 1998, Rowan-Robinson et al. 1998, Guiderdoni et al. 1998, Sanders 1999, Dey et al. 1999, Efstathiou et al. 2000, Silk & Devriendt 2000, Serjeant et al. 2001, Takeuchi et al. 2001).

Considering mergers as a possible formation mechanism of Ultraluminous Infrared Galaxies both at high and low redshift, as well as their significant infrared emissions, Wang (1999), Wang & Biermann (2000) discussed the effects of galaxy mergers on the strong evolution of IRAS $60\ \mu m$ deep survey within a binary aggregation galactic evolutionary scheme. In this model, the bright tail of the infrared luminosity function is simulated in a consistent way for both the density and luminosity evolution due to the decrease of the merger fration with cosmic time and a merger triggered infrared burst phase. They found a luminosity dependent infrared burst phase is crucial for the interpretation of the steep slope within flux range of $10\,mJy \sim 1\,Jy$ by IRAS $60\ \mu m$ deep survey. Which means dusty starburst galaxies or AGNs from gas rich mergers at high redshift may experience an infrared burst phase around a transition redshift $z \sim 1$, and fade quickly within the merger time scale of that epoch. The more massive merger systems could have such infrared emission enhanced to a higher level and decrease even faster. This kind of speculation is based on the observational reality that ULIGs are usually more than a factor of 20 brighter than normal starburst galaxies. Although the detailed mechanism for such enormous infrared emission is still unclear, it is believed to be related with a special stage of the merger process when the dust mass and temperature are both dramatically increased (Kleinmann & Keel, 1987, Taniguchi & Ohyama 1998). Recent numerical simulation on the evolution of dusty starburst galaxies by Bekki & Shioya (2001) shows that there is a very strong photometrical evolution during the merger process of two gas rich disks, and a dramatic change of the spectral energy distribution (SED) around cosmic time scale $T \sim 1.3\,Gyr$, when the two disks of the merger become very close to suffer from violent relaxation and the star formation becomes maximum ($\sim 378\,M_{\odot}yr^{-1}$). The infrared flux in this case could increase by one magnitude, especially for the far infrared wavelength range ($60\,\mu m \sim 90\,\mu m$) in emitting frame.

The redshift distribution of the contributing sources for the steep slope at faint IRAS $60\,\mu m$ counts by the model of Wang & Biermann (2000) shows that the infrared burst phase around $z \sim 1$ could have comparable significance as the local IR sources. The question which occurs to us is then whether such an infrared burst phase, or such a population of ULIGs could also sufficiently account for the strong evolution seen in other infrared wavelengths, especially at the ISOCAM $15\,\mu m$, ISOPHOT $90\,\mu m$, $170\,\mu m$ and SCUBA $850\,\mu m$. We thus try to make a reconciliatory evolution model which could fit for at least the present statistics of the multi-wavelength deep surveys.

In this paper, we will first review the binary aggregation galaxy evolution model by Wang (1999), Wang & Biermann (2000) in section 2, where starburst/AGN activities may be triggered during the merger process as well as an infrared burst phase from gas rich mergers around redshift one. Meanwhile, we will discuss the SED template we adopt in our calculation for the nearby starburst galaxies and a possible strong evolution of the spectral energy distribution of the dusty starburst merging systems at $z \sim 1$. We thus could further investigate whether the infrared burst phase from gas rich mergers around redshift $z \sim 1$ is sufficient to account for the strong evolution also detected by ISO and submillimetre deep surveys. One set of cosmological parameters, namely $H_0 = 50\,km/s/Mpc$, $\Omega = 0.3$ and $\Lambda = 0.7$ is adopted in the calculation.

## 2. Model

We adopt in this study the binary aggregation dynamics based on the Smoluchowski equation (1916) within a merger-driven galaxy evolutionary scheme, which simulates the evolution of luminosity function due to galaxy mergers and predicts the redshift dependent luminosity function of a population of galaxies evolving forwards in time from the formation epoch to match the observed local luminosity function, number counts and space distribution etc. Studies of Cavaliere & Menci (1993, 1997) shows that this method could include more dynamics to describe a further step in galaxy-galaxy interactions within the scheme of direct hierarchical clustering (DHCs), and probably could help to alleviate some intrinsic problems in DHC scenario, such as the overproduction of small objects as well as the difficulty of a reconciliation between the excess of faint blue counts and the flat local luminosity function. The numerical technique to solve the Smoluchowsky equation is a Monte-Carlo approach for the inverse-cascade merger tree. The readers are referred to Cavaliere & Menci (1993, 1997), Wang (1999), Wang & Biermann (2000) for the details of the dynamics and the techniques.

Considering of different evolutionary characteristics of different morphologies, we adopt in our study a multi-component model which contains starburst galaxies, dust shrouded AGNs and spiral galaxies as three major classes of infrared emitting sources. The local luminosity functions of the spiral and starburst galaxies at $60\,\mu m$ from Saunders (1990), and that of Seyferts from Ruch et al. (1993) are used to normalize the Monte-Carlo simulation. We adopt the mass-light relation of blue starburst galaxies, which is given by Cavaliere & Menci (1997) in a study of the excess of faint blue galaxies in optical surveys. The abundances of dust-shrouded AGNs are set to be 50% and 80% at local and high redshift based on the statistics from Hubble Space Telescope imaging survey of nearby AGNs and the cosmic X-ray background (Malkan et al. 1998, Gilli et al. 1999).

The modelling of a luminosity dependent ultraluminous infrared burst phase from gas rich mergers is described in detail by Wang & Biermann (2000). Here we first give a brief review of the basic dynamics and the template SED we adopt in our model for the infrared luminous sources. We introduce in this section also the construction of a SED for the dusty starburst mergers at $z \sim 1$, normally with the luminosity $L_{ir} > 10^{12}\,L_\odot$, in order to further investigate such an evolutionary scenario at mid and far-infrared wavelengths from ISO deep survey. Considering that star formation is triggered by mergers and proportional to $M_{gas}/\tau$ ($\tau$ is the dynamical interaction time scale), Cavaliere & Menci derived a mass-light ratio for dwarf galaxies, $L/L_* = (M/M_*)^\eta$ (where $\eta = 4/3$, if the cross section is purely geometrical). $L_* \propto f(z, \lambda_0, \Omega_0)$ could be used to describe a redshift dimming, or a luminosity evolution. A power law prescription of $f(z) \propto (1+z)^\beta$ is adopted in the model. Simplifying the color and K- corrections, they roughly get $L_B \propto \frac{L_*}{M_*^\eta}\, M^\eta = \frac{L_*(0)}{M_*^\eta\, f(z)\, M^\eta}$. We assume in our model a luminosity ratio $\frac{L_{60}}{L_B} \propto M^{\acute{\eta}}$, which is consistent with current understanding of the nature of ULIGs, where people normally believe that the extremely infrared bright phase is due to the starburst merger events with far-infrared luminosity $L_{ir}$ enhanced both by the accumulating of the dust mass and the increasing of the dust temperature. This burst phase could enhance the infrared luminosity by a factor of about 20 over that of normal starburst galaxies (Kleinmann & Keel, 1987, Taniguchi & Ohyama 1998, Bekki & Shioya 2001). We give $L_{60} \propto \frac{L_*(0)}{M_*^\eta}\, f(z)\, M^{\eta+\acute{\eta}}$. $\acute{\eta} = 1 \sim 1.2$ is adopted in the calculation, which not only reasonably represents an infrared enhancement of about a factor of 20 for a typical ULIG with mass of $10^{12}\,M_\odot$ (the mass increases about one magnitude over that of normal starburst galaxies), but successfully interprets the steep slope of IRAS number counts. The scaling factor of the mass-light ratio here is normalized by local luminosity function of IRAS deep survey. We found from our best fit results that a population of infrared starburst sources, especially with spheroidal morphology would experience very strong evolution in the past. A rate of $\beta = 3.7$ in the luminosity evolution $f(z) \propto (1+z)^\beta$ since a transition redshift $z \sim 1$, indicates a very strong evolution for such a population of starburst galaxies which is at least comparable to, if not stronger than QSOs (Roche et al. 1998, Lonsdale 1995, Pearson & Rowan-Robinson 1996, Dole et al. 1998, Rowan-Robinson et al. 1998, Sanders 1999, Franceschini et al. 1988, 2001). A differential dimming is simulated by $L_{ir}(z - \delta z) \propto L_{ir}(z)^{1-\zeta}$ below a transition redshift $z \sim 1$, in order to match the observed local luminosity function by IRAS deep survey. The simulation gives a best value $\zeta \sim 0.4$. Also this power law suppression includes another physical reality, that the infrared luminous galaxies at the bright tail of the luminosity function become gas poor faster than the less luminous ones. Besides the merger rate decrease with cosmic time, this physical effect is very important for a good fit of the steep slope at IRAS $60\,\mu m$ number counts within flux range of $100\,mJy \sim 1\,Jy$.

We reviewed above the dynamics and some important physical parameters in current study, which are the same as those used in the previous paper of IRAS $60\,\mu m$ number counts fitting for a consistency (Wang 1999, Wang & Biermann 2000). In the following, we will start to construct the spectral energy distribution for dusty starburst mergers around redshift $z \sim 1$, in order to extrapolate the calculation to mid- and far-infrared wavelengths. Since the unclear nature of the Ultraluminous Infrared Galaxies at high redshift, we do not have a good understanding of the dust environment and properties in these sources. An optically thin, single-temperature dust model is adopted as a first order approximation for a modified blackbody continuum of temperature $T$ at far-infrared wavelength in this calculation. The formula is simply given by $S_\lambda = B_\lambda(T)\,\tau_\lambda \propto B_\lambda\, K_\lambda$. Where $\tau_\lambda = K_\lambda\, \rho\, dl$ is the dust opacity, and $K_\lambda$ the dust absorption coefficient ($K_\lambda \propto \lambda^{-\beta}$ of $\beta \simeq 1-2$). In this case, the received flux at wavelength $\lambda$ is $S_\lambda = \frac{\Gamma\, \lambda_e^{-\beta}\, B(\lambda_e, T)}{4\,\pi\, dL^2\,(1+z)}$, where $\Gamma$ is the scaling factor for a conservation of the dust absorbed energy and re-emitting energy, $\lambda_e = \lambda/(1+z)$ is the wavelength in emitting frame. A flux ratio in observer's frame could be derived by $\frac{S_{\lambda_1}}{S_{\lambda_2}} = \frac{\lambda_{1e}^{-\beta}\, B(\lambda_{1e}, T)}{\lambda_{2e}^{-\beta}\, B(\lambda_{2e}, T)} \sim (\frac{\lambda_2}{\lambda_1})^{\beta+5}\, e^{\frac{h\,C}{k}\,(\frac{1}{\lambda_2} - \frac{1}{\lambda_1})\,\frac{1+z}{T}}$, where $h$ is Plank's constant, $k$ is Boltzmann's constant and $C$ is the speed of light. With a reasonable assumption for the dust emissivity power $\beta$ and the dust temperature $T$, we can easily extend our calculation to far-infrared wavelength. The mid-infrared emission is more complicated than that of far-infrared which could be well described by a single temperature blackbody spectrum by cold, big grain dust. The MIR emission properties are usually dominated by radiation field of heated small grains and PAHs. These dust grains are normally heated stochastically, and are not in thermal equilibrium with ambient radiation field. Thus the MIR continuum is mostly like a power law spectrum. In this calculation, we will not go to a detailed modelling of the MIR emission feature. Instead, we only modify the template SED of starburst galaxy Arp220 by Silva et al. (1998), with the observational correlations of $S_{15}/S_{60}$ by IRAS, ISOCAM deep surveys for the ultraluminous case ($L_{ir} > 10^{11}\,L_{\odot}$) to represent the dusty starburst merging system around redshift one. The color ratio of $S_{15}/S_{60}$ for the ULIGs show a factor of about 5 lower than the mean value of the whole sample, which may imply a very complicated process to heat small grains during the merger process (Chary & Elbaz 2001, Aussel et al. 2000, Dunne et al. 2000, Saunders et al. 2000). Although there are many indications that the MIR continuum is correlated with the temperature of big grain dust (Dale et al. 2001), there is still no exact modelling for such a process. Our goal of this paper is to construct a simple SED for those luminous starburst mergers based on various obsevational correlations, which not only represents the observed trend for individual samples of certain luminosity bin ($L_{ir} > 10^{12}\,L_{\odot}$), but matchs the statistical results from the multiwavelength deep surveys. The number of sources $dN$ in comoving volume $dV$ within flux range $S_\lambda$ to $S_\lambda + dS_\lambda$, measured at wavelength $\lambda$, is defined by: $dN = \rho(L_\lambda, z)\, dV\, \frac{dL_\lambda}{dS_\lambda}\, dS_\lambda$, $\frac{dL_\lambda}{dS_\lambda} = \frac{4\,\pi\, d_L^2}{K(L_\lambda, z)}$, where $K(L_\lambda, z) = \frac{L_{\lambda_e}\, d\lambda_e}{L_\lambda\, d\lambda}$ is the K-correction, and $d_L$ is the luminosity distance in a $\Lambda$ dominated universe.

## 3. Results and discussions

The exact broad-band spectra of faint IR sources is still not well defined. Considering deep surveys at various IR/submm wavelengths would help to simultaneously constrain the evolution properties and the typical spectral energy distribution of such sources. We show in this section the comparison of our model prediction with the ISOCAM $15\,\mu m$ survey data, IRAS $60\,\mu m$, FIRBACK $90\,\mu m$ and $170\,\mu m$, as well as the SCUBA $850\,\mu m$ data. We also calculated the redshift distribution of these sources within a certain flux range and the cosmic infrared background level. Fig. 1 to Fig. 3 is the model prediction for the European Large Area ISO Survey (ELAIS). This survey covered 12 $deg^2$ of the sky in four main area and was carried out with the ISOPHOT instrument onboard the Infrared Space Observatory ISO, which is at least an order of magnitude deeper than the IRAS $100\,\mu m$ survey. It therefore provides an important constraint for our model of galaxy evolution. The majority of the optical identification of the detected sources are interacting pairs or small groups of galaxies, which may indicate that the ELAIS sample includes a significant fraction of luminous infrared galaxies from galaxy mergers. Although there are some discrepancy on the data reduction, previous estimations show that the source counts are mostly in aggreement with strongly evolving starburst models, with a quick increase of the fraction of ULIGs towards high redshift (Serjeant et al. 2001, Efstathiou et al. 2000, Matsuhara et al. 2000). From our calculation, we see in Fig. 1 to Fig. 3 that the differential number counts of $90\,\mu m$, $15\,\mu m$ and $170\,\mu m$ for a reliable subset of the detected sources could be sufficiently accounted for by the infrared burst phase when a population of ultraluminous infrared sources with $L_{ir} > 10^{12}\,L_{\odot}$ could be produced by the merger-triggered starburst/AGN activities at $z \sim 1$ (Kawara et al. 1998, Elbaz et al. 1999, Efstathiou et al. 2000, Dole et al. 2001). The enormous infrared emission, especially at far-infrared wavelength is modelled by a modified black body spectrum which we discussed already in the previous section. We assume that the starburst merging system has a similar MIR emission feature as Arp220, but modified by the observed flux correlation of $S_{15}/S_{60}$ from IRAS, ISOCAM deep surveys. We found from the calculation that the dust temperature of these starburst merging system would be higher than that of the nearby starburst ULIGs Arp220, with dust temperature $T = 65\,K$ and $\beta = 1.5$ for a best fit result. Fig. 4 shows our model fitting for the differential counts of IRAS $60\,\mu m$ deep survey, and Fig. 5 is the integrated number counts of submillimeter SCUBA deep survey at $850\,\mu m$ (Hacking et al. 1987, Moshir et al. 1992, Blain et al. 1999, Barger et al. 1999). Almost all the number counts could be reproduced quite well by such an evolutionary scenario, except for the ISOCAM $15\,\mu m$ differential number counts where our model prediction shows a slight excess at the bright part of $S_{15} \sim 2\,mJy$. The reason could be that we simply adopt the mid-infrared emission feature of Arp 220 for the case of the starburst merging system around $z \sim 1$. We hope to improve the current results by further on theoretical modelling and the observational constraints for the emission properties at mid infrared bands from future infrared missions.

The infrared background in this calculation gives $2.4nW\,m^{-2}\,sr^{-1}$ at $15\mu m$, $1.9nW\,m^{-2}\,sr^{-1}$ at $60\mu m$, $3.8nW\,m^{-2}\,sr^{-1}$ at $90\mu m$, $10.6nW\,m^{-2}\,sr^{-1}$ at $170\mu m$, which all in consistent with current upper limits from TeV detection, COBE results and the resolved fraction of the CIRB by the deep ISO surveys (Funk et al., 1998, Guy et al. 2000, Hauser & Dwek 2001).

The redshift distribution of the ISOCAM $15\mu m$ contributing sources within the detected flux range ($0.1\,mJy \sim 10\,mJy$) from our model calculation is shown in Fig. 6. It gives a rough statistics that these luminous infrared sources cover a wide redshift range of $0.5 \sim 2.5$, peak at $z \sim 1$. Comparing our model prediction and the redshift distribution of $15\mu m$ sources with $S_{15} > 120\mu Jy$ in the HDF North and the z-distribution of sources in the CFRS field (Cohen et al. 2000, Aussel et al. 2001, Flores et al. 1999), we found the starburst mergers at $z \sim 1$ in our model would be the good candidates of a strongly evolving population which results in the strong evolution in mid- and far-infrared deep surveys. Recent redshift estimation from sub-mm follow up of 10 known FIRBACK

170$\mu m$ ISO sources by Scott et al. (2000) suggests that they are in a redshift range of $0 \sim 1.5$, still consistent with our current model prediction. However, these redshift determinations are strongly depend on the assumption of the dust properties. We need further on accurate measurements for the robust constraints of the models. We discussed in a previous paper that shifting the peak redshift of these ULIGs by a factor of 2 could affect the source count fitting of IRAS 60$\mu m$ deep survey, especially for a low redshift peak ($z < 0.5$). A strong evolution of the ULIGs till $z \sim 1$ may be a most reasonable case for the existing model constraints from both the infrared deep surveys and the cosmic infrared background upper limits from high energy TeV detections, as well as the indicated star formation history by UV/optical deep surveys (Lilly et al. 1996, Connolly et al. 1997, Madau et al. 1998).

We plot out the redshift distribution of ULIGs ($\nu L_\nu > 10^{12}\, L_\odot$), in order to understand the evolution properties of the ULIGs from mergers in our model. A quick increase of the number density of ULIGs till $z \sim 1$ is seen in Fig. 7, which is actually consistent with a scenario where galaxy merger rate increase dramatically during that epoch from various observations and theoretical considerations (Zepf & Koo 1989, Burkey et al. 1994, Carlberg 1992, Carlberg et al. 1994). However, the number density of ULIGs decrease beyond $z \sim 2-3$, which may reflects a stage when merger pairs are mostly dwarfs, the infrared emissions are less than $10^{12}\, L_\odot$ even with intensive starburst activities triggered by mergers. In this scenario, an infrared luminous tail of the luminosity function may form till late epoch around $z \sim 1$, with enormous infrared emission enhancement.

There is still no firm statistics for the classification of starbursts and AGNs from current spectroscopies. We thus adopt the observed AGN local luminosity function of Rush et al. (1993) as a model constraint, and assume in whole our calculation that the observed starburst galaxies and Seyferts follow the same evolution track, based on a naive thinking that starburst/AGN may both triggered from galaxy interactions. We know the subtle differences of the dust emission properties could result in a different fraction of their contribution, which is still far too early for us to discuss here. We thus adopt only the SED of the Cloverleaf quasar which represents a phase poor in cold gas, as well as the dust enshrouded phase of F10214+4724 as two kinds of typical AGN templates in our calculation. We know from the result that the AGN contribution is only a small fraction and our current model prediction is within the concepts of the present understanding of this issue, i.e. the starburst powered ULIGs are dominating over the AGN powered ones (Fig. 7), it may take over at higher redshift and higher luminosity case (Lutz et al. 1998, Tran et al. 2001).

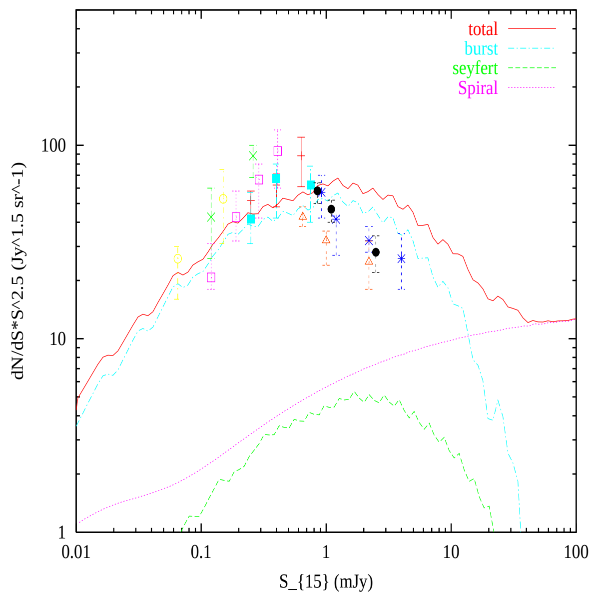


**Fig. 1.** The model prediction of the differential number counts of ISOCAM 15 $\mu m$ normalized to the Euclidean law ($dN/dS * S^{2.5}$). The data points are the normalized counts from a variety of ISO deep surveys (Elbaz et al. 1999). The line represents the sum of the contribution from three populations (starburst galaxies, spiral galaxies and Seyferts). In our model, we assume the population of starburst galaxies, especially with spheroidal morphology, are the products of galaxy mergers which would experience the infrared emission enhancement because of the merger triggered starburst activities. Their contribution to the ISOCAM 15 $\mu m$ deep survey is shown in the Figure by the dot-dashed line from our Monte-Carlo simulation. The dotted line corresponds to the non-evolving spiral galaxies, and the short dashed line are from Seyferts, which is assumed to have the same evolutionary track as starburst galaxies in a galaxy evolutionary scheme with galaxy mergers.

## 4. Summary

We simply described a galaxy evolutionary scenario with galaxy mergers in a CDM cosmology, where starburst and AGN activities may be triggered by the merger events. With a reasonable assumption of the ultraluminous infrared burst phase from gas rich mergers at high redshift, we sucessfully interpreted the strong evolution of IRAS 60 $\mu m$ deep survey, leaving the infrared background still in a low limit of $1.9\, nW\, m^{-2}\, sr^{-1}$, consistent with the upper limits from recent TeV $\gamma$ ray detection of nearby Blazars.

Lacking of comprehensive and confidential understanding of the gas and dust environment of faint ISO sources, especially the starburst merging system at $z \sim 1$, we adopt the template spectral energy distribution such as Arp220 by Silva et al. (1998) as typical for nearby starburst galaxies. Meanwhile, we construct a simple SED for the starburst mergers at $z \sim 1$. The far-infrared emission in such a system is modelled by a single temperature, optical thin dust law with the modified black body emission. The MIR emission feature is assumed to be similar as Arp 220, but modified by the flux correlation from IRAS and ISOCAM observations. In this case, we can further investigate such a merger-driven galaxy evolutionary scenario at other infrared and submillimeter wavelengths by ISO and SCUBA deep surveys. Our calculation shows that

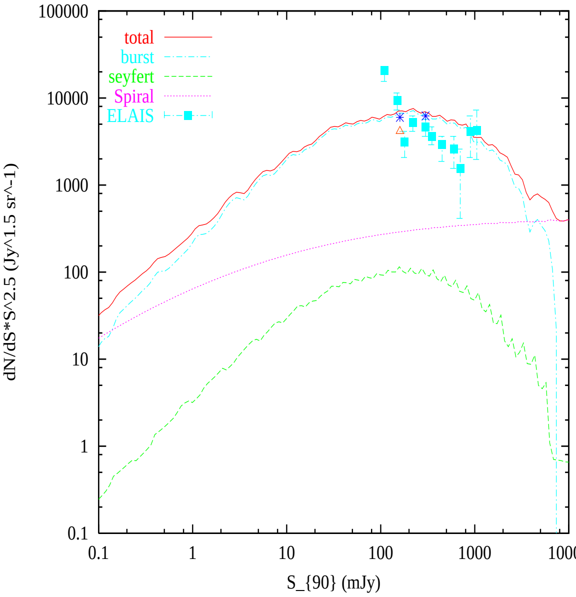


**Fig. 2.** The fitting of the ELAIS differential source count at 90 $\mu m$. The data are from C-90 filter of the C100 ISOPHOT detector array [filled squares: Efstathiou et al. 2000; open trianguler: Linden-V$\phi$rnle et al. (2000); star: Juvela et al. (2000)]. The meaning of the lines is the same as in Fig.1

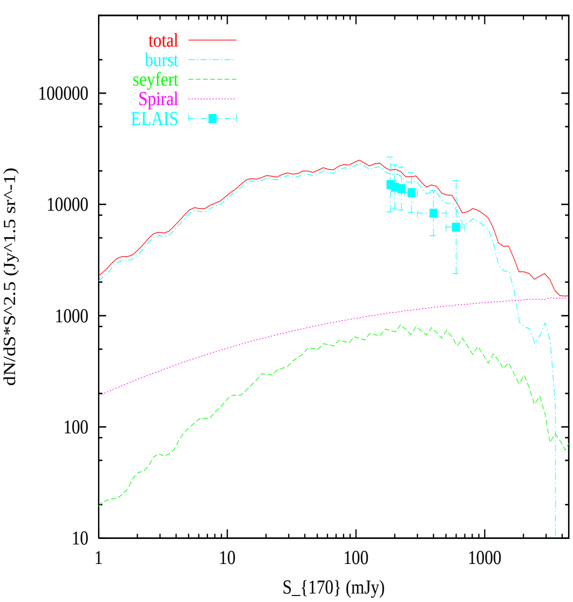


**Fig. 3.** The result of FIRBACK 170 $\mu m$ ISO deep survey differential number count fitting from our model calculation. The data are from Dole et al. (2001).

the current results of multi-wavelength deep surveys at ISOCAM 15$\mu m$, ELAIS 90$\mu m$, FIRBACK 170$\mu m$, IRAS 60$\mu m$ and SCUBA 850$\mu m$ number counts could be sufficiently accounted for by the merger-triggered infrared enhancement at $z \sim 1$ from our model with the dust temperature ($T \sim 65\,K$, and $\beta \sim 1.5$), slightly higher than the local starburst galaxy Arp220. Future accurate redshift measurements and multiband photometries would provide us a robust model check.

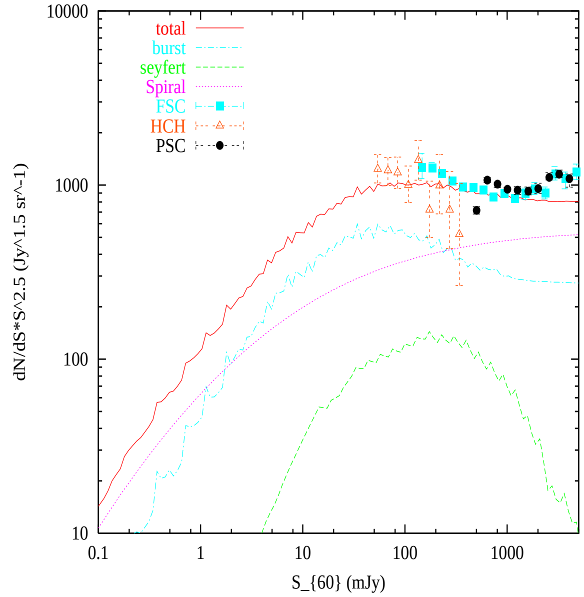


**Fig. 4.** This is the fitting of the IRAS 60 $\mu m$ source counts from three major infrared emitters (starburst galxies, spiral galaxies and Seyferts). The source counts of starburst galaxies and Seyferts are from the Monte-Carlo simulation where the evolution of both activities are triggered by the galaxy-galaxy interactions/mergers during the structure formation. The spiral galaxy is assumed to have a mild constant star formation history, i.e. a non-evolving population in our calculation. The data are from IRAS Point Source Catalogue (1985)(PSC), Hacking et al. IRAS deep survey (HCH), FSC from deep surveys by Moshir et al. (1992) and Saunders (1990).

The background level at these wavelengths are estimated from our model calculation, which gives $2.4 nW\,m^{-2}\,sr^{-1}$ at 15$\mu m$, $3.8 nW\,m^{-2}\,sr^{-1}$ at 90$\mu m$, $10.6 nW\,m^{-2}\,sr^{-1}$ at 170$\mu m$, still compatible with the cosmic infrared background level both from the upper limit of high energy TeV $\gamma$ ray detection of nearby Blazars and COBE, ISO results.

The redshift distribution of the luminous infrared sources within ISOCAM 15 $\mu m$ detection flux range ($0.1\,mJy \sim 10\,mJy$) from our calculation is plotted out in Fig. 6. The redshift distribution of these sources cover a wide redshift range of $0.5 \sim 2.5$ and peak around a mean redshift of $z \sim 1$.

We plot out also the redshift distribution of ULIGs ($\nu L_\nu > 10^{12} L_\odot$) in Fig. 7. It shows a strong increase of the ultraluminous infrared population till a mean redshift $z \sim 1$, and decrease by a factor of about 2 already at $z \sim 2 - 3$. This probably is the major difference of our current calculation from other models, and indicates that the infrared luminous tail may be produced at the cosmic epoch of $z \sim 1$, when the merger rate and the size of parent galaxies are all suitable for such an infrared emission enhancement.

A brief discussion on the fraction of contribution from AGNs and starbursts from our calculation is given in section 3. We assumed in the model a similar evolutionary

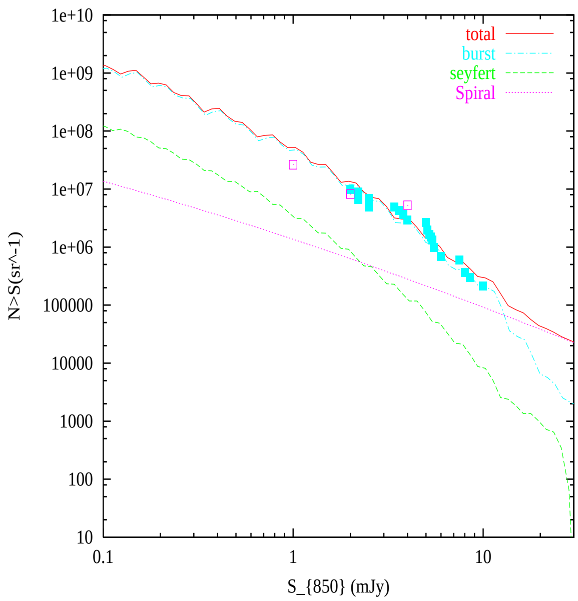


**Fig. 5.** Integral number counts at $850\,\mu m$. The open squares are from Blain et al. (1999), and the filled squares are from Barger, Cowie and Sanders (1999). The meaning of lines are the same as in previous figures.

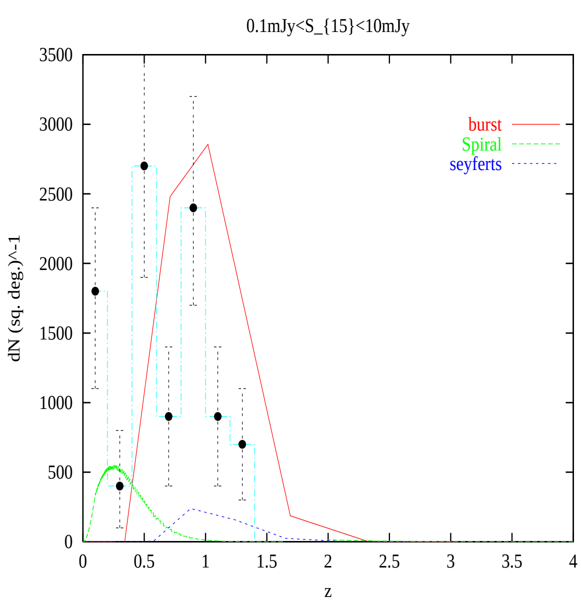


**Fig. 6.** The redshift distribution of three infrared contributors (starburst galaxies, spiral galaxies and AGNs) at flux range of $0.1\,mJy \sim 10\,mJy$ at $15\,\mu m$ from our model calculation. It shows the redshift of these ISO far-infrared sources would cover a wide range and peak towards $z \sim 1$. We include also the AGNs contribution in our model based on the observed AGN Local Luminosity Function from Rush et al. (1993) and a reasonable evolution assumption as a realistic model constraints, which we know now is only a small fraction of the starburst contribution and at mean redshift $z \sim 1$ from our calculation. Further follow-up classification of these luminous infrared sources would help us to study the AGN-starburst correlation and give a robust model check.

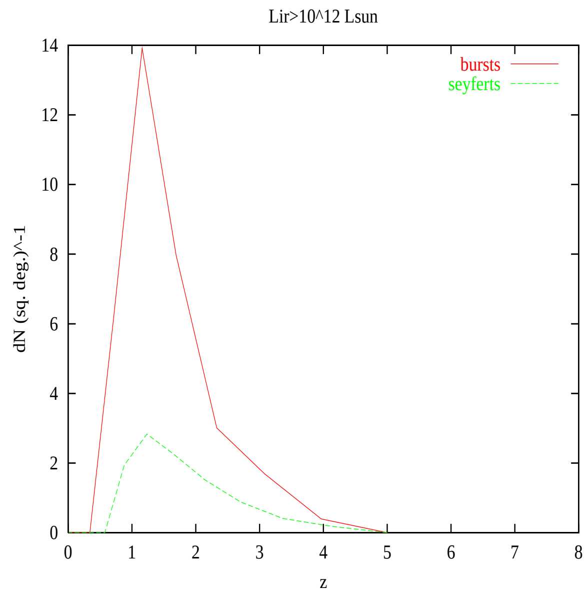


**Fig. 7.** The redshift distribution of ultraluminous infrared sources (starbursts or AGNs) with $L_{ir} > 10^{12}\,L_{\odot}$ from our model calculation. Obviously, the number density of the ultraluminous infrared sources increase dramatically till $z \sim 1$, but quickly decrease afterward. This indicates that the bright tail of ultraluminous infrared sources would be efficiently formed around that cosmic epoch by galaxy mergers. However, these numbers are very rough estimation, a different SED of the AGNs could slightly change the fraction of their contribution.

track for the starburst galaxies and AGNs based on the concept that both AGNs and starbursts may be triggered by galaxy interactions, where the AGN population is constrained by the observed Local Luminosity Function of Seyferts from Rush et al. (1993). Since the uncertainty of the dust properties of ULIGs, especially for those harboring an AGN in the center, we adopt here only two typical SED templates of Cloverleaf QSO and F10214+4724. In this case, we give a rough estimation for the relative abundance of AGN and starburst powered ULIGs ($L_{ir} > 10^{12}\,L_{\odot}$) of $\sim 1/5$, which seems to be close to the recent submillimeter observations of Chandra X-ray sources (Barger et al. 2001, Almaini et al. 1999, Gunn & Shanks 2001).

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